

Activated BIOCHAR with VERMICOMPOST as an alternative PEAT substitute

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ABSTRACT

Biochar produced from a mixed feedstock of ash, beech and oak under slow pyrolysis process (500-550 °C) was amended with vermicompost in 1: 2 ratio (w/w) to make nutrient enriched vermi-biochar. Experiments were performed to examine if this vermi-biochar could replace peat as a growth medium in greenhouse production of vegetables. Replacement of peat is an environmental goal as peat represent at least partly an unrennewable source which decomposition contributes to greenhouse gases and global warming. Red Cherriette Radish (*Raphanus sativus* L. var. *sativus*) was selected as a test plant and was raised in vermi-biochar mixed with peat in volumetric ratios 0:100 (pure peat, control 1), 40:60, 60:40, 70:30, 80:20, and 100: 0 (pure vermi-biochar, control 2). The peat was a commercial fertilizer enriched growth medium commonly used by farmers. Growth parameters such as root and shoot weights and brix percentage were measured. The results showed that vermi-biochar used in a rate of 40-70 %, but also vermi-biochar alone, significantly increase fresh root weight and overall biomass compared to peat soil alone. The study implies that vermi-biochar can replace all the peat used in the greenhouse production of radish and even enhance the yield of the produced biomass.

Keywords: Biochar; organic amendment; vermicompost; growing media; peat

INTRODUCTION:

Globally, increased use of peat as a growing substrate has led to an over-exploitation of this resource and a speeding up of the release of stable carbon to the atmosphere [1]. Off the estimated 400 million hectares of peatland, 11 million metric tonnes are exploited every year [2]. Peat, with its 3 % cover of the global land, has a potential to store carbon as same quantities of the entire forests available in the world [3]. Almost 15 % of the global peatland has already been drained and ongoing breakdown of peat is resulting in 5 % of the global CO₂ emissions every year [4]. Most of this is due to cultivation on the drained peat fields but part of it is for exploration, and used as a growth substrate in horticulture, like in greenhouse production of vegetables, flowers, and other plants. The highly porous nature, enhanced water holding capacity, high CEC, and recalcitrant nature has led to a dependency of using peat as a major growing substrate in the world. This can be illustrated by figures from Europe, where more than 90 % of the growing substrate based enterprise is depending on peat [5]. Meanwhile, the European Commission has initiated a program to discard peat use, however not yet brought into action [6].

Considering the peatland emissions and accelerating climate change, a need for sustainable, alternative growing media is essential. The world needs to replace the peat used in the agriculture sector. CO₂ emissions from peatland use are high all over the world. South East Asian countries are emitting 2 billion tons of CO₂, emissions similar to 3/10th of global emissions from fossil source usages [7][8]. Indonesia alone constitutes 58 % of CO₂ emissions from peatland exploitation [9]. In addition, almost half of peatland area available in Nordic and Baltic countries has already been drained, causing 80 megatons (Mt) of CO₂ emissions per annum, which equals to 25 % of total CO₂ emissions from these regions [3].

One alternative to peat could be biochar-based growth substrates. Biochar is produced from pyrolysis of wood, crop residues, and other organic wastes, under limited oxygen conditions. The result is a highly porous, stable product, having some of the same physical properties as of peat, but instead of contributing to CO₂ emissions biochar has the potential to store carbon. On a global scale, biochar can reduce 1.8 gigatons of CO₂ emissions per annum, nullifying 12% of the

total global greenhouse emissions [10], symbolizing a great emission reduction potential.

Research on using coconut fibres, coir, and various composted organic materials has been done to test alternatives to peat [11], however, found not effective enough to replace the peat completely. Indeed, there is a need for an alternative and sustainable substrate. Our point of departure is that biochar represents such an alternative. Studies have shown that post-treatment of biochar with compost can increase the soil carbon and nutrient contents, and can improve other physical and chemical properties, enhancing its value as a growth substrate [12][13].

We followed the idea that activated biochar is more enriched than pure biochar and had the hypothesis that different mixtures of biochar and vermicompost, hereafter termed vermi-biochar (biochar activated with vermicompost) could replace the peat as a growing substrate in horticulture. The objective of our study was to evaluate the properties of biochar and to determine the fine tune ratios of biochar and vermicompost mix to form vermi-biochar capable of replacing peat. We also liked to optimize the mix of vermi-biochar and peat substrate to be capable to for reducing or replacing peat in greenhouse production of vegetables.

MATERIALS AND METHODS

The biochar was produced from a mixed woodchips of ash (*Fraxinus excelsior*), beech

(*Fagus sylvatica*) and oak (*Quercus robur*) selected uniformly (≤ 5 mm), to produce in a new pyrolyzer unit (B300, Biochar Energy Systems P/L., Bendigo, Australia) at temperature of 500–550 °C at Skjærgården farm, Vestfold, Norway (59°N, 10°E). Biochar was then mixed with vermicompost in a 1: 2 ratio (w/w) to form vermi-biochar (B_v). Greenhouse experiments were set up with a pure commercial peat growth substrate as a control 1, vermi-biochar as control 2 and different mixtures of these substrates as other treatments. A detailed overview of growing media composition used is shown in Table 1.

The experiments were carried in containerized plastic trays using a RCBD design and with having altogether six treatments and four replications per treatment. Seven seeds of Red Cherriette Radish (*Raphanus sativus* L. var. *sativus*) were placed in each replicate treatment. Irrigation water was supplemented as per the plant need, looking after the dryness. Fertigation was done with Calcinite (15.5 % N) and Kristalon (9-5-25+Mg+S+micronutrient) throughout the growing period (July 2- August 1, 2017). A total of 2.6L per 10m² of Calcinite (pH 6.65, EC 0.235 mS/m) was applied as follows: 1L 8 July, 0.8L 19 July and 24 July. Kristalon (pH 6.45, EC 0.268 mS/m) was applied as: 1L per 10m² 11 July and 17 July, 0.8L per 10m² 22 July. Germination and early plant growth was followed daily. Final plant readings and harvesting were done after 30 days, measuring total root and shoot weights, root diameter, and brix percentage.

Table 1: Overview of growing media

Treatment		Details
T1	P ₁₀₀	100 % commercial peat substrate
T2	P ₆ B _{v4}	60 % peat + 40 % Vermi-biochar
T3	P ₄ B _{v6}	40 % peat + 60 % Vermi-biochar
T4	P ₃ B _{v7}	30 % peat + 70 % Vermi-biochar
T5	P ₂ B _{v8}	20 % peat + 80 % Vermi-biochar
T6	B _v	100 % Vermi-biochar

Statistical analysis was performed by R-Studio software and two-ways variance analysis (ANOVA) was applied along with Tukey's HSD to measure difference among the substrates at a 95 % significance level.

RESULTS AND DISCUSSION

Chemical Characteristics of growth substrates

Chemical properties such as pH, heavy metals present, PAH, and plant nutrient contents of the produced pure biochar and vermi-biochar

were measured and compared to European Biochar Certificate (EBC) regulations Versions 6.3 E (<http://www.european-biochar.org>)(Table 2;3;4;6).

For the analysis of biochar, samples were selected uniformly from the produced mixed pile. The pure biochar had an alkaline nature with a pH at 9.5, and the biochar had high electrical conductivity (EC at 68.5 mS/m) and a high ash content (48.3 %).

Table 2: Properties of wooden chips, biochar and EU requirements for standardizing the biochar [1].

Parameters	Bio-char	Woodchips	Requirements	
			EU Basic	EU Premium
pH (CaCl ₂)	9.5	-		
Total C (%)	57.1	48.9		
H ₂ (%)	0.5	5.6		
Fe ₂ O ₃ (%)	4.3	3.8		
CaO (%)	5.3	11.1		
K ₂ O (%)	3.9	5.6		
MgO (%)	1.6	2.8		
Na ₂ O (%)	3.1	3.1		
Total N (%)	0.14	0.18		
Sulfur (%)	0.05	0.07		
Ash content, 815 °C (%)	46.8	2		
Pb(mg kg ⁻¹)	8	<2	<150	<120
Cd(mg kg ⁻¹)	<0.2	0.3	<1.5	<1.0
Cu(mg kg ⁻¹)	17	2	<100	<100
Cr (mg kg ⁻¹)	27	9	<90	<80
Hg(mg kg ⁻¹)	<0.07	<0.07	<1	<1
Ni(mg kg ⁻¹)	13	5	<50	<30
Zn(mg kg ⁻¹)	98	33	<400	<400
As(mg kg ⁻¹)	-	-	<13	<13
Mn(mg kg ⁻¹)	667	67	-	-
Total PAH (mg kg ⁻¹)	10	-	<12	<4

C in biochar was measured in particles sizes >600 µm

The mixed vermi-biochar (B_v) had a slightly lower pH and EC than pure biochar, this due to

the lower pH and EC in the vermicompost (V) than in pure biochar.

Table 3: Comparison of EC and pH of vermi-biochar, peat, and peat mixed vermi-biochar substrates [1].

Treatments	EC (mS/m)	pH
B _v	85.1±15.2	8.79±0.03
P ₁₀₀	45.4±3.9	8.01±0.18
P ₂ B _{v8}	30.4±0.4	8.47±0.08
P ₃ B _{v7}	38.2±4.8	8.83±0.28
P ₆ B _{v4}	45.6±4.5	8.37±0.10
P ₄ B _{v6}	61.3±6.5	8.06±0.04
V	57.0 ± 0	7.5 ± 0

Values are means ± SD.

Addition of vermi-compost, having a high organic matter content compared to pure biochar, enhanced the organic matter content of vermi-biochar (Table 4). Higher C/N ratio of substrate might lead to nitrogen immobilization. However, additional fertigation was done with Calcinat and Kristalon during the growing period, supplying

the nutrients essential for plants. Regarding germination, P₁₀₀ and P₂B_{v8} seemed to boost early seedling growth, but there was not a significant difference between the substrates on overall germination percentage (results not shown).

Table 4: Organic content of Substrate [1].

Treat-ment	Organic Matter(%)	Total C (%)	Total N (%)	C/N Ratio
B _v	59.9±2.3	48.0±3.5	0.77±0.09	62.5±3.7
P ₁₀₀	80.2±0.8	42.8±0.4	1.00±0.01	42.7±0.9
P ₃ B _{v7}	67.9±0.5	48.9±1.8	0.81±0.06	60.6±3.2
V	22.2	No data	No data	No data

Values are means ± SD.

Effects on plant growth

Radish is a root crop, fresh root weight is essential for the farmer from a commercial perspective. The study showed that vermi-biochar and vermi-biochar enriched peat substrates resulted in significantly higher yield than peat soil alone (Fig. 1). Average

overall biomass (fresh root and shoot weights), was the highest in P₃B_{v7} (with 24.7gm) but the differences were not significant compared to the other vermi-biochar mixtures (Table 5). Also for this parameter, peat resulted in the lowest yield (18.07 gm). P₃B_{v7} resulted in 27 % higher biomass production than peat alone.

Table 5: Measured Growth parameters of Radish.

Treatmen t	Fresh Shoot Weight (gm)	Fresh Root Weight (gm)	Total Biomass (gm)	Brix %	Root Diameter (cm)
P ₁₀₀	3.9±0.2 a	14.1±0.8b	18.1 ±0.9b	4.7±0.4 a	2.7±0.12 a
P ₆ B _{v4}	4.7±0.3 a	18.6±0.9a	23.3 ±1.1a	4.1±0.1 a	3.2±0.06 a
P ₄ B _{v6}	4.6±0.2 a	19.2±0.7a	23.8 ±0.8a	4.8±0.6 a	3.2±0.09 a
P ₃ B _{v7}	4.6±0.4 a	20.1±1.9a	24.7 ±2.3a	5.0 ±0.0a	3.2±0.12 a
P ₂ B _{v8}	4.3±0.5 a	19.9±1.6a	24.2 ±2.0a	4.1±0.2 a	3.2±0.09 a
B _v	4.6±0.1 a	18.5±0.7a	23.1 ±0.6a	4.7±0.7 a	3.2±0.04 a

Values are means \pm SE, in a column followed by different alphabets are significantly different at $p < 0.05$ (Tukey's HSD test).

Our result corresponds well to [14] that reported a 22 % yield increase by adding 50 % biochar to the growth substrate compared to using peat alone in the production of *Calathea rotundifolia*.

Furthermore, our study tested the increased use of vermi-biochar, and we were able to get good results in radish even with 100 % vermi-biochar as a growth substrate. Several studies

have shown that using biochar with peat in rates from 25 % to 75 % have been optimal [15][11][13]. We applied an activated biochar with vermicompost, and we used this in a dose of 40 % to 100 % in peat mixtures with no any negative effects. As per the guidance made by [6], to use biochar in higher doses, activated biochar by vermicompost, has the potential to replace peat at growth substrate.

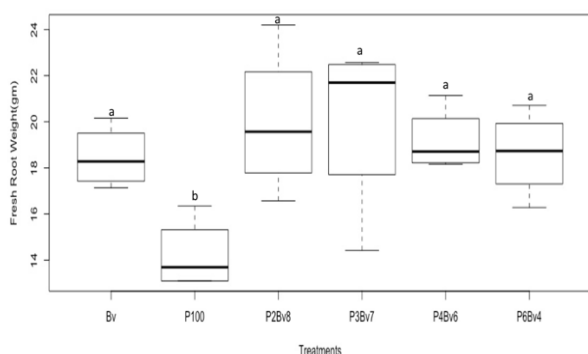


Fig. 1: Effect of Substrates on Fresh Root Weight of Radish. Substrates having different alphabetical letter are significantly different to each other.

Plant nutrients and heavy metal content

Vermi-biochar and peat enriched substrates as used in our study had a higher elemental composition (P, K, Mg, Al, Ba, Fe, and Zn) than normal peat soil (Table 6). Our analysis showed that the lead (Pb) concentration was higher in pure peat than in the vermi-biochar and mixed substrates. The concentration of all heavy metals (Zn, Pb, Cd, Cr, Ni, As) in vermi-biochar and mixed substrate were in a line of premium graded biochar, as labeled by EBC. This symbolizes the potential of activated biochar to supply the essential nutrients and a prospect of using vermi-biochar even under organic fertigation regime.

In our study, biochar based substrates, with its higher nutrient holding and supplement ability, led to an increased biomass, including an increased root biomass. Increased phosphorus concentration in vermi-biochar and mixed substrates could be one explanation to this, as phosphorus is known to have such effects [16]. Other explanations could be enhanced by the availability of certain elements due to a higher pH [17]. We showed that increased with the use of vermi-biochar. Certainly, plant growth was not affected, even though, that pH was higher than commonly recommended for radish [18].

Table 6: Elements constitution of substrates through inductively coupled plasma mass spectrometry (ICP-MS)

Element (mg kg ⁻¹)	Vermibiochar (B _v)	Commercial peat (P ₁₀₀)	Mixture (P ₃ B _{v7})
P	1513±18	511±36	1270±35
K	5498±178	3291±97	5067±102
Ca	10442±99	26074±427	15628±262
Mg	25603±845	20192±799	20273±218
Al	12782±495	8589±211	12088±255
Ba	168±6.0	89±4.2	165±6.5
Fe	12866±489	8598±188	13760±297
Na	2195±36	3532±110	3264±97
Pb	9.0±0.5	15.7±0.9	8.3±0.2
Zn	110±1.5	26.2±0.5	85.7±0.3
Mn	425±14	173±4.9	405±9.3
Cd	0.63±0.03	0.40±0.0	0.53±0.03
Cr	44.3±4.6	128±12.6	271±29.0
Ni	28.3±3.0	85.2±8.2	179±19.4
As	0.7±7.9E-17	0.73±3.3E-02	0.7±7.9E-17

Values are means±SE

Water holding capacity and other properties

Water holding capacity of vermi-biochar and mixed substrates is slightly lower than peat soil. This was solved by frequent water supplement during the growing period, and using this kind of growth substrate highlight the need for continuously supplying the plants with water and nutrients essential for proper

plant growth. The increased percentage of finer particles (< 0.5, 0.5 – 2, 2 mm) in vermi-biochar compared to what is found in peat (Table 7) reflects an increased surface area, what could be a positive property coming to using this as growing media in horticulture [19].

Table 7: Sieve size distribution of substrates.

Sieve Size (mm)	B _v (%)	P ₆ B _{v4} (%)	P ₂ B _{v8} (%)	P ₁₀₀ (%)	P ₃ B _{v7} (%)	P ₄ B _{v6} (%)
5	10	5.9	8.7	7.7	4.5	8.9
4	2	5.9	4.3	7.7	4.5	2.2
2	10	17.6	8.7	30.8	18.2	8.9
0.5-2	60	52.9	39.1	46.2	50.0	44.4
< 0.5	18	17.6	39.1	7.7	22.7	35.6

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REFERENCES:

- [1] Karki, R. (2018). Vermibiochar as alternative to peat as growing substrate for greenhouse vegetables (Master's thesis): Inland Norway University of Applied Sciences.
- [2] Strack, M. (2008). Peatlands and climate change: IPS, International Peat Society.
- [3] Barthelmes, A., Couwenberg, J., Risager, M., Tegetmeyer, C., & Joosten, H. (2015). Peatlands

- and Climate in a Ramsar Context: A Nordic-Baltic Perspective (Vol. 2015544): Nordic Council of Ministers, Copenhagen, Denmark.
- [4] Joosten, H. (2009). The Global Peatland CO₂ Picture: peatland status and drainage related emissions in all countries of the world: Wetlands International, Wageningen. <https://www.wetlands.org/>
- [5] Kern, J., Tammeorg, P., Shanskiy, M., Sakrabani, R., Knicker, H., Kammann, C., et al (2017). Synergistic use of peat and charred material in growing media— an option to reduce the pressure on peatlands? Journal of Environmental Engineering and Landscape Management, 25(2):160-174.
- [6] Lehmann, J., & Joseph, S. (2015). Biochar for environmental management. Science, technology and implementation: Routledge.
- [7] Hooijer, A., Silvius, M., Wösten, H., & Page, S. (2006). PEAT-CO₂, Assessment of CO₂ emissions from drained peatlands in SE Asia. Delft Hydraulics report Q3943/2006:36.
- [8] Joosten, H. (2015). Peatlands, climate change mitigation and biodiversity conservation: An issue brief on the importance of peatlands for carbon and biodiversity conservation and the role of drained peatlands as greenhouse gas emission hotspots (Vol. 2015727): Nordic Council of Ministers.
- [9] Oleszczuk, R., Regina, K., Szajdak, L., Höper, H., & Maryganova, V. (2008). Impacts of agricultural utilization of peat soils on the greenhouse gas balance. Peatlands and Climate Change In: M. Strack (Ed.), International Peat Society, Jyväskylä, Finlandia, pp. 70-97.
- [10] Woolf, D., Amonette, J. E., Street-Perrott, F. A., Lehmann, J., & Joseph, S. (2010). Sustainable biochar to mitigate global climate change. Nature Communications 1:56.
- [11] Fascella, G. (2015). Growing substrates alternative to peat for ornamental plants. In Soilless culture- Use of substrates for the production of quality horticultural crops: InTech Open. DOI:10.5772/59596
- [12] Agegnehu, G., Srivastava, A., & Bird, M. I. (2017). The role of biochar and biochar-compost in improving soil quality and crop performance: a review. Applied Soil Ecology 119: 156-170.
- [13] Steiner, C., & Harttung, T. (2014). Biochar as a growing media additive and peat substitute. Solid Earth 5(2):995.
- [14] Tian, Y., Sun, X., Li, S., Wang, H., Wang, L., Cao, J., & Zhang, L. (2012). Biochar made from green waste as peat substitute in growth media for *Calathea rotundifolia* cv. Fasciata. Scientia Horticulturae 143:15-18.
- [15] Dumroese, R. K., Heiskanen, J., Englund, K., & Tervahauta, A. (2011). Pelleted biochar: Chemical and physical properties show potential use as a substrate in container nurseries. Biomass and Bioenergy 35(5):2018-2027.
- [16] Xiang, Y., Deng, Q., Duan, H., & Guo, Y. (2017). Effects of biochar application on root traits: a meta-analysis. GCB Bioenergy 9(10): 1563-1572.
- [17] Eissenstat, D. M. (1992). Costs and benefits of constructing roots of small diameter. Journal of Plant Nutrition 15(6-7):763-782.
- [18] Margenot, A. J., Griffin, D. E., Alves, B. S., Rippner, D. A., Li, C., & Parikh, S. J. (2018). Substitution of peat moss with softwood biochar for soil-free marigold growth. Industrial Crops and Products 112:160-169.
- [19] Jayasinghe, G. (2012). Sugarcane bagasses sewage sludge compost as a plant growth substrate and an option for waste management. Clean Technologies and Environmental Policy 14(4): 625-632.